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A NOVEL BUCK CONVERTER FOR LOW VOLTAGE HIGH CURRENT APPLICATIONS

V.Vanitha

PG Scholar, Karpaga Vinayaga College of Engineering & Technology, Chennai, India[1]
surenthuya@gmail.com

ABSTRACT

This paper presents a pulse width modulation dc–dc non isolated buck converter using three-state switching cell, organized by two active switches, two diodes, and two coupled inductors. One part of the load power is processed by the active switches, reducing the peak current through the switches to half of the load current, as higher power levels can be attained by the propose topology. The size of reactive elements, i.e., inductors and capacitors, is also decreased since the ripple frequency of the output voltage is twice the switching frequency. Due to the fundamental characteristics of the topology, total losses are distributed between all semiconductors. Another advantage of this converter is the reduced region for discontinuous conduction mode when compared to the conventional buck converter or, in other words, the operation range in continuous conduction mode is increased, as confirmed by the static gain plot. The theoretical approach is detailed complete qualitative and qualitative analyses by the application of the three-state switching cell to the buck converter operating in non overlapping mode ($D < 0.5$). Besides, the mathematical analysis and development of an experimental prototype rated at 1 kW are carried out. The main experimental results are presented and adequately discussed to clearly identify its claimed advantages.

Key Words— Buck converter, Dc–Dc converters, three-state switching cell (3SSC).

I. INTRODUCTION

PULSEWIDTH modulation (PWM) dc–dc converters are widely employed in numerous applications, e.g., audio amplifiers [1], uninterruptible power supplies [2], fuel cell powered systems [3], and fork lift vehicles [4] In order to dazed such limitation, several soft switching methods have been introduced in the literature. Soft switching is theoretical to reduce the overlap between voltage and current during the commutation, and can be classified in either active or passive methods, as one must choose between the above-mentioned snubbers for a given application. Active methods can reduce the switching losses by using auxiliary switches. As the power rating increases, it is frequently required to secondary converters in series or in parallel. By using interleaving techniques in high current applications, the currents through the switches become just portions of the input current [11]. Interleaving successfully doubles the switching frequency and also partially cancels the input and output ripples, as the size of the energy storage inductors and differential-mode EMI filter in resulting operations can be reduced .

I.A. Continuous Conduction Mode

In CCM mode the switch has two sub-intervals in a switching period.
Considering,
D1- the switch-on duty cycle
D2- the diode-on duty cycle

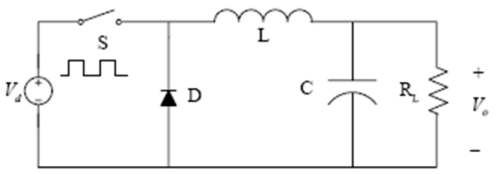

Fig 1.1 Buck Converter

D1 = Vo/ (Vi + Vo)

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where, Vi and Vo are the input and output voltages of buck converter. This can be rewritten to obtain the output voltage of the converter in CCM mode,

$$V = \frac{D\,V}{(1-D)}$$

D1max occurs at Vi(min) and D1min occurs at Vi(max). The DC voltage conversion ratio of buck converter with CCM is obtained as,

$$\frac{V}{V} = \frac{D}{1-D} = M$$

B .Discontinuous Conduction Mode

In DCM the switching period is divided into three sub-intervals. The third time interval of operation cycle is non-zero, not that either inductor current is discontinuous. The three distinct time intervals are namely D1 Ts , D2 Ts and D3 Ts with D1 + D2 + D3 = 1 for a constant switching frequency. D3 is the switch and diode off ratio. The output voltage of the converter in DCM is

$$V = \frac{D}{D}V$$

The DC voltage conversion ratio is obtained as

$$M = \frac{D}{D} = \frac{V}{V}$$

II. COUPLED INDUCTOR

The coupled inductor consists of two separate inductors wound on the same core; they typically come in a package with the same length and width as that of a single inductor of the same inductance value, only slightly taller. The price of a coupled inductor is also typically much less than the price of two single inductors. The windings of the coupled inductor can be connected in series, in parallel, or as a transformer. Most of the coupled inductors have the same number of turns i.e., a 1:1 turns ratio but some newer ones have a higher turns ratio. The coupling factor K, of coupled inductors is naturally around 0.95, much lower than a tradition transformer's coefficient of greater than 0.99.

The leakage inductance of the coupled inductors can be working to control the diode current falling rate and to improve the diode reverse-recovery problem. A coupled inductor with a lower-voltage-rated switch is used for floating the voltage gain (whether the switch is turned on or turned off). Furthermore, a passive regenerative snubber is employed for absorbing the energy of stray inductance so that the switch duty cycle can be operated under a wide range, and the related voltage gain is higher than other coupled-inductor-based converters .

By replacing the input inductors of DC/DC converters with a cell designed by a coupled inductor and a diode leads to a family of converters with high voltage ratio. The energy stored in the leakage inductance is transferred to the load through the diode. Thus the stress in the switch is also significantly reduced.

III. BUCK CONVERTER WITH COUPLED INDUCTOR

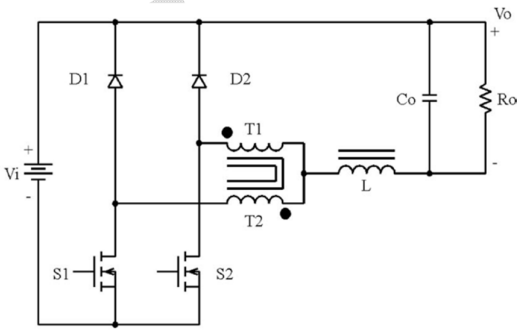

Fig 3.A. Circuit diagram

The circuit configuration of the proposed DC to DC converter is shown in Fig 3. This topology is basically derived from a conventional buck converter by replacing the input inductor by a coupled inductor. The turns ratio of the coupled inductor increases the voltage gain and the secondary winding of the coupled inductor is in series with a switched capacitor for further increasing the voltage. In Fig 3 S1 is the floating active switch. The primary winding N1 of a coupled inductor is similar to the input inductor of the conventional boost converter, except that capacitor C1 and diode D1 recycles the leakage-inductor energy from N1. The secondary winding N2 is connected with another pair of capacitor C2 and diode D2 which recycles the leakage inductor energy from N2. Now N2, C2 and D2 all three are in series with N1.

In the proposed system, the dc supply can be obtained by rectifying the standard 250V, 50Hz ac supply. So that the converter can be directly operated from standard ac supply. In this converter two power switches are connected in parallel to primary of high frequency transformer for large load currents. To achieve large step-down voltage ratios the power switches are turned ON and OFF alternatively with a time gap so that there will be Four switching states.

State1: Switch1 ON, Switch2 OFF
State2: Both Switch OFF
State3: Switch1 OFF, Switch2 ON
State4: Both switch OFF

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The desired output voltage is achieved efficiently using PID closed loop control. The output is measured using R-Load. The Voltage measurement block measures the instantaneous voltage between two electric nodes. The output provides a Simulink signal that can be used by other Simulink blocks. The output of the system can be seen through the scope.

3.1 MODE 1 OPERATION

Stage 1 [t0, t1]:

Initially, switch S1 is turned ON, while switch S2 is turned OFF. The current through the inductor is divided in two parts. The first part flows through T1 and D2 with energy being delivered to the load. The second part flows through T2 and S1. Current sharing is continued since the number of turns for T1 and T2 is the same.

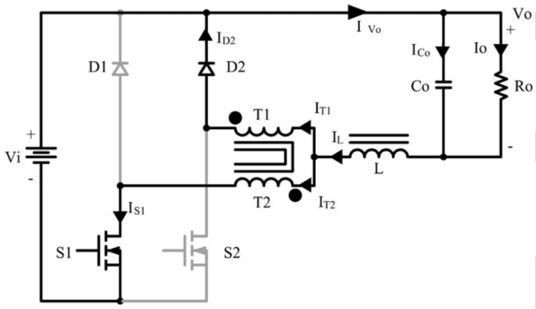


Fig 3.1 Circuit diagram of mode 1 operation

3.2 MODE 2 OPERATION

Stage2 [t1, t2]:

Switch S1 is turned OFF, while switch S2 remains OFF. The voltage across inductor L is inverted. Diode D1 is forward biased while D2 remains conducting. The energy stored in L during the previous stage is then transferred to the load. The current flows through T1T2, according to the given polarity, what reasons the magnetic flow in the primary to be null. The current returns to the source analogously to the preceding stage. This stage finishes when S2 is turned ON.

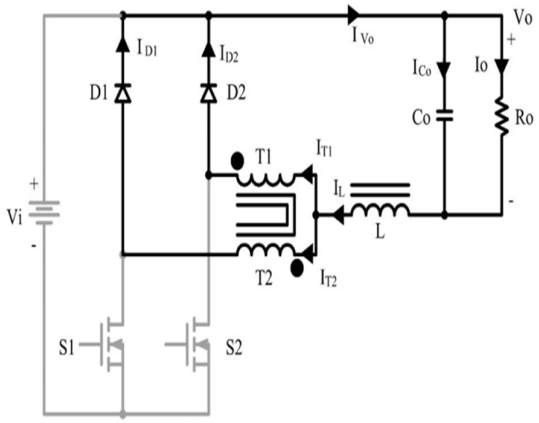


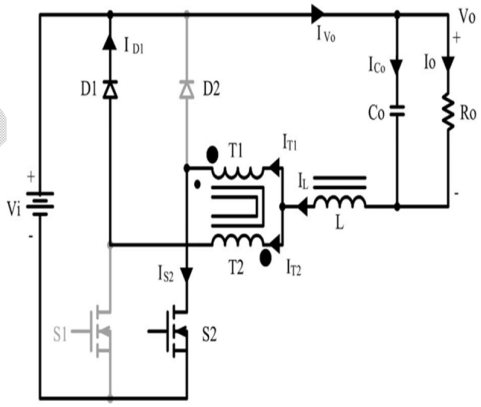
Fig 3.2 Circuit diagram of mode 2 operation

3.3 MODE 3 OPERATION

Stage 3 [t2, t3]:

Due to symmetry of the circuit, this stage is similar to the first one, although switch S2 is turned ON instead and S1 remains turned OFF. Diode D1 keeps conducting and D2 is reverse biased.

Fig 3.3 Circuit diagram of mode 3 operation



3.4 MODE 4 OPERATION

Stage 4[t3, t4]:

Switch S1 is turned OFF, while switch S2 remains OFF. The voltage across inductor L is inverted. Diode D1 is forward biased while D2 remains conducting. The energy stored in L during the earlier stage is then transmitted to the load. The current yields to the source analogously to the previous stage. This stage varnishes when S2 is turned ON.

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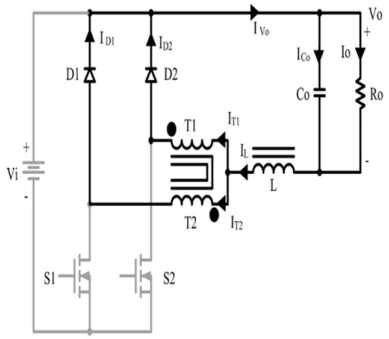
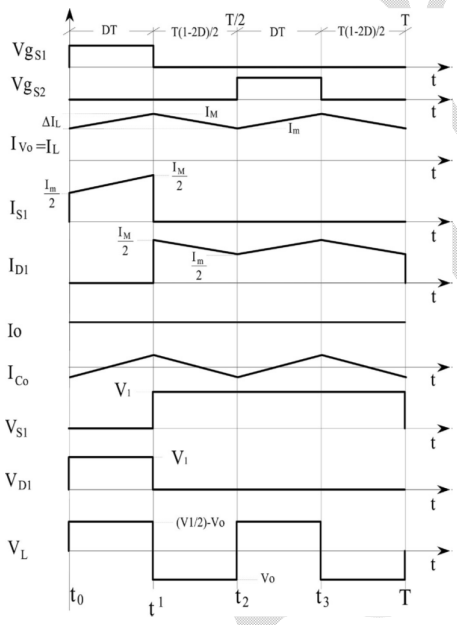


Fig 3.4 Circuit diagram of mode 4 operation

THEORETICAL OUTPUT WAVEFORM



IV.SIMULATION RESULTS

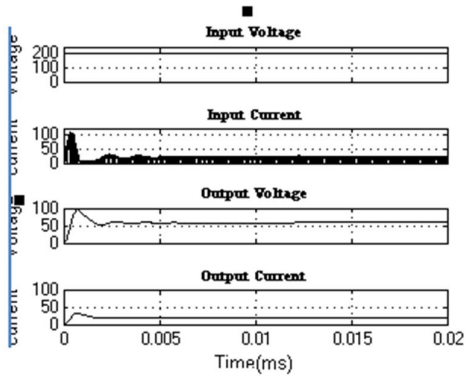


Fig 4.1 Input and output waveform of voltage and current waveform

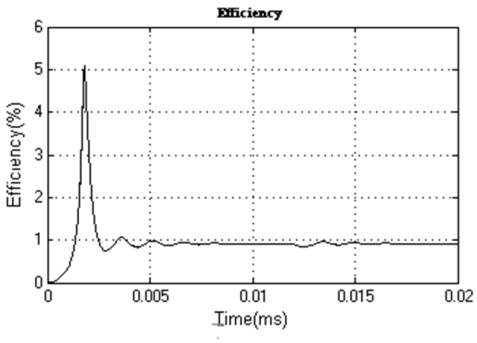


Fig 4.2 Efficiency waveform

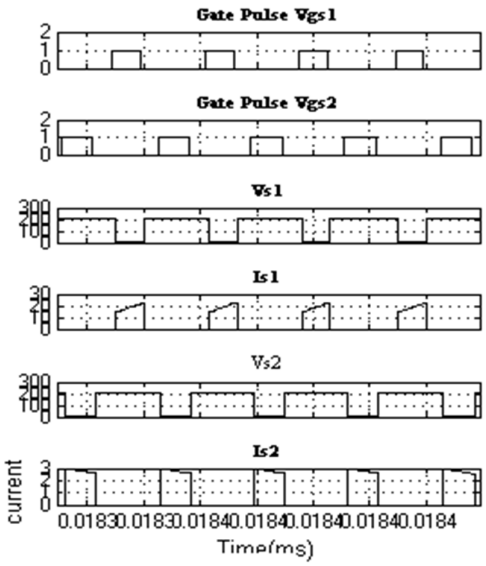


Fig 4.3 Output waveforms 1

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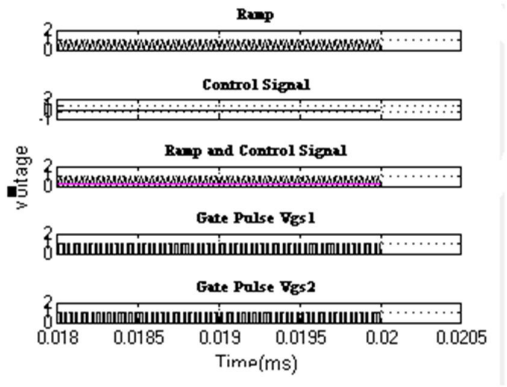

Fig 4.4 Output waveform 2

The proposed method can be seen as the integration of the interleaving technique and three SSC. The following expedient characteristics can be then addressed to the introduced topology:

1) Reduced dimension, weight, and capacity of magnetics, which are designed for twice the switching frequency analogously to the interleaved buck converter.

2) The current stress through each main switch is equal to half of the total output current, allowing the use of semiconductors with lower current ratings.

3) Losses are spread among the semiconductors, leading to better heat distribution and subsequently more efficient use of the heat sinks.

4) Part of the input power, i.e., 50%, is directly transferred to the load through the diodes and the coupled inductors
(auto transformers), and not through the main switches .As a consequence, conduction and switching losses are
reduced. This is the main difference between the functionality of this approach and that of the interleaved buck topology.

5) The use of three SSC permits the parallel connection of switches and, therefore, inexpensive power devices and drives can be used.

6) Energy is transferred from the source to the load during most part of the switching period, which is a distinct characteristic
of the proposed converter, since in other buck type converters, it only occurs during half of the switching period. As a consequence, reduction of current peaks and also conduction losses are expected.

7) The drive circuit of the main switches becomes less complex because they are connected to the same reference node, what does not occur in the interleaved buck converter.

DESIGN SPECIFICATIONS

Parameter	Value
Source voltage	Vi=200 V
Inductor current ripple (20% of the input current)	IL=3.33 A
Switching frequency	fs=30 kHz
Rated output power	Po=1 kW
Output voltage	Vo=60 V
Output voltage ripple	Vo=0.6 V

By choosing arbitrarily the ripple current, the inductance can be determined as

$$L = \frac{(\quad)}{\Delta} = \frac{}{\Delta} \quad (7)$$

Considering the maximum ripple current which represents the worst case, the inductance can be obtained by

$$L = \frac{}{\Delta} \quad (8)$$

The critical inductance, whose value assures operation in CCM, is given by

$$Lcrit = \gamma \frac{}{} \quad (9)$$

The output capacitor can be determined as

$$Co = \frac{\Delta}{\Delta} \quad (10)$$

Where,
ΔVo is the output voltage ripple [V] and
fs is the switching frequency [Hz].

V. CONCLUSION

A dc–dc buck converter based on the 3SSC has been attainable. When the 3SSC is employed, the current is distributed among the semiconductors. Furthermore, only part of the energy from the input source flows through the active switches, while the remaining part is directly transferred to the load without being processed by these switches, i.e., this energy is delivered to the load through passive components, such as the diodes and the transformer windings. Despite the increase in the number of semiconductors, the current levels on these devices are reduced, enabling the use of inexpensive switches and simplified command circuits because the isolated drive is not required like in the interleaved buck converter. In front of these characteristics, its use is recommended for high-power high-current applications where the traditional approach may be inadequate, while good current sharing is achieved.

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In addition, the overall losses are distributed among all semiconductors,
reducing the heat sink efforts. The reactive components operate with twice the switching frequency, with significant
reduction in weight and volume of such components. Considering the operation in NOM (D < 0.5) and the same ratings, the following characteristics can be addressed with the 3SSC-based converter if compared with the conventional buck topology:
1) Augmented number of semiconductor elements
2) Oprating area in CCM is wider
3) Ripple current through the inductor is reduced, in addition to the currents through the switches
4) Reactive elements are designed for twice the switching frequency, causing the required precarious inductance to be
smaller, for example;
5) only 50% of the power is delivered to the load through the main switches due to the magnetic coupling between the
transformer winding. Besides, an significant advantage of the proposed converter operating in OM ($D > 0.5$) is the continuous wildlife of the input current, which is essentially discontinuous in the conventional buck converter, what may lead to the use of an input filter for
some applications.

REFERENCES

[1] M. Berkhout and L. Dooper, "Class-D audio amplifiers in mobile applications," *IEEE Trans. Circuits Syst. I, Reg. Papers*, vol. 57, no. 5,pp. 992–1002, May 2010.
[2] E. K. Sato,M. Kinoshita, Y.Yamamoto, and T. Amboh, "Redundant high density high-efficiency double-conversion uninterruptible power system,"*IEEE Trans. Ind. Appl.*, vol. 46, no. 4, pp. 1525–1533, Jul./Aug. 2010.
[3] S. V. Araujo, R. P. Torrico-Bascop´e, and G. V. Torrico-Bascop´e, "Highly efficient high step-up converter for fuel-cell power processing based on three-state commutation cell," *IEEE Trans. Ind. Electron.*, vol. 57, no. 6,pp. 1987–1997, Jun. 2010.
[4] Z. Amjadi and S. S. Williamson, "Power-electronics-based solutions for plug-in hybrid electric vehicle energy storage and management systems," *IEEE Trans. Ind. Electron.*, vol. 57, no. 2, pp. 608–616, Feb. 2010.
[5] G. Yao, Y. Shen,W. Li, and X. He, "A new soft switching snubber for the interleaved boost converters," in *Proc. 35th Annu. IEEE Power Electron. Spec. Conf.*, Jun. 2004, pp. 3765–3769.
[6] I.Matsuura, K. M. Smith, Jr., and K. M. Smedley, "A comparison of active and passive switching methods for PWMconverters," in *Proc. 29th Annu. IEEE Power Electron. Spec. Conf.*, May 1998, vol. 1, pp. 94–100.
[7] G. Hua and F. C. Lee, "Soft-switching techniques in PWM converters," *IEEE Trans. Ind. Electron.*, vol. 42, no. 6, pp. 595–603, Dec. 1995.
[8] K. Fujiwara and H. Nomura, "A novel lossless passive snubber for softswitching boost-type converters," *IEEE Trans. Power Electron.*, vol. 14, no. 6, pp. 1065–1069, Nov. 1999.
[9] D. S. Oliveira, Jr., C. E. A. Silva, R. P. Torrico-Bascop´e, F. L. Tofoli, C. A. Bissochi, Jr., J. B. Vieira, Jr., V. J. Farias, and L. C. de Freitas, "Analysis, design, and experimentation of a double forward converter with soft switching characteristics for all switches," *IEEE Trans. Power Electron.*, vol. 26, no. 8, pp. 2137–2148, Aug. 2011.
[10] J. P. Rodrigues, S. A. Mussa,M. L.Heldwein, and A. J. Perin, "Three-level ZVS active clamping PWM for the dc–dc buck converter," *IEEE Trans. Power Electron.*, vol. 24, no. 10, pp. 2249–2258, Aug. 2009.
[11] Y. Jang and M. M. Jovanovic, "Interleaved boost converter with intrinsic voltage-doubler characteristic for universal-line PFC front end," *IEEE Trans. Power Electron.*, vol. 22, no. 4, pp. 1394–1401, Jul. 2007.
[12] D. J. Perreault and J. G. Kassakian, "Distributed interleaving of paralleled power converters," *IEEE Trans. Circuits Syst. I, Fundam. Theory Appl.*,vol. 44, no. 8, pp. 728–734, Aug. 1997.
[13] S. V. Araujo, R. P. Torrico- Bascop´e, and G. V. Torrico-Bascop´e, "Highly efficient high step-up converter for fuel-cell power processing based on three-state commutation cell," *IEEE Trans. Ind. Electron.*, vol. 57, no. 6, pp. 1987–1997, Jun. 2010.
[14] S. V. Araujo, R. P. Torrico-Bascop´e, G. V. Torrico-Bascop´e, and L. Menezes, "Step-up converter with high voltage gain employing threestate switching cell and voltagemultiplier," in *Proc. Power Electron. Spec. Conf.*, 2008, pp. 2271–2277.
[15] R. A. da Camara, C.M. T. Cruz, and R. P. Torrico-Bascop´e, "Boost based on three-state switching cell for UPS applications," in *Proc. Brazilian Power Electron. Conf.*, 2009, pp. 313–318.
[16] G. V. Torrico-Bascope, R. P. Torrico-Bascop´e, D. S. Oliveira, Jr., S. V. Ara´ujo, F. L. M. Antunes, and C. G. C. Branco, "A generalized high voltage gain boost converter based on three-state switching cell," in *Proc. IEEE Int. Symp. Ind. Electron.*, 2006, pp. 1927–1932.

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[17] G. V. Torrico- Bascop´e, R. P. Torrico-Bascop´e, D. S. Oliveira, Jr., S V. Ara´ujo, F. L. M. Antunes, and C. G. C. Branco, "A high step-up converter based on three-state switching cell," in *Proc. IEEE Int. Symp Ind. Electron.*, 2006, pp. 998–1003.
[18] R. P. Torrico-Bascop´e, C. G. C. Branco, G. V. Torrico-Bascop´e, C. M. T. Cruz, F. A. A. de Souza, and L. H. S. C. Barreto, "A new isolated DC–DC boost converter using three-state switching cell," in *Proc. Appl. Power Electron. Conf. Expo.*, 2008, pp. 607–613.
[19] E. E. Landsman, "A unifying derivation of switching regulator topologies," in *Proc. IEEE Power Electron. Spec. Conf.*, 1979, pp. 239–243.
[20] S. Busquets-Monge, S. Alepuz, and J. Bordonau, "A bidirectional multilevel boost–buck dc–dc converter," *IEEE Trans. Power Electron.*, vol. 26, no. 8, pp. 2172–2183, Aug. 2011.
[21] J. P. R. Balestero, F. L. Tofoli, R. C. Fernandes, G. V. Torrico-Bascop´e, and F. J. M. Seixas, "Power factor correction boost converter based on the three-state switching cell," *IEEE Trans. Ind. Electron.*, vol. 59, no. 3, pp. 1565–1577, Mar. 2012.
[22] M. Roslan, K. H. Ahmed, S. J. Finney, and B.W.Williams, "Improved instantaneous average current-sharing control scheme for parallel-connected inverter considering line impedance impact in microgrid networks," *IEEE Trans. Power Electron.*, vol. 26, no. 3, pp. 702–716, Mar. 2011.
[23] N. Genc and I. Iskender, "DSP-based current sharing of average current controlled two-cell interleaved boost power factor correction converter," *IET Power Electron.*, vol. 4, no. 9, pp. 1015–1022, 2011.